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SYSTEM PERFORMS ACTIVE LOAD-PULL MEASUREMENTS

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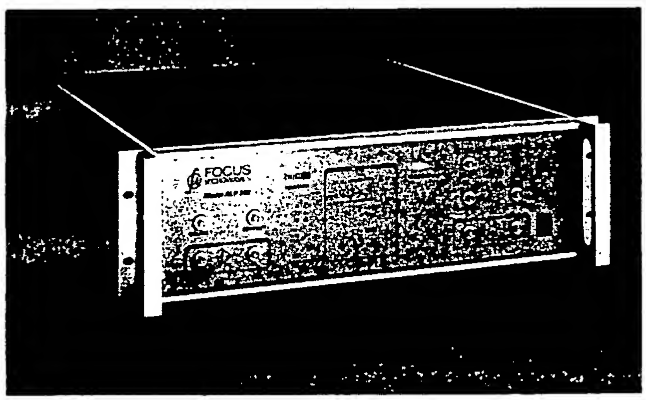
COVER FEATURE

SYSTEM PERFORMS ACTIVE LOAD-PULL MEASUREMENTS

This fast and simple-to-use test system provides high-power device measurements with high reflection factors.

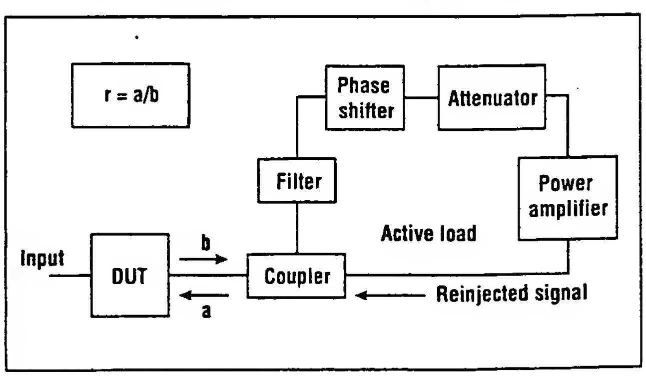
LOAD-PULL characterization of RF power transistors is critical for designing the high-intercept-point power amplifiers used in digital communications systems. Existing test systems that rely on mechanical and electronic tuners are complex to use and are limited in capability compared to a novel load-pull system that emulates a load to a device under test (DUT) by means of active feedback. The Active Load Pull System (ALPS), developed by Focus Microwaves, Inc. (Pointe-Claire, Quebec, Canada), is currently available for measurements from 0.8 to 2.8 GHz.

Existing power characterization techniques include passive and active load-pull systems. Passive load-pull systems employ mechanical tuners that are moved by means of stepper motors or electronic systems based on switched diodes to emulate different impedance loads. An alternative approach, through the use of an active feedback loop, samples a signal from the output of a DUT, processes that signal, then reinjects the signal into the DUT's output port, thus emulating a precisely-controlled impedance load.



1. The model ALPS-308 active load-pull system is designed for measurements from 0.8 to 2.8 GHz. The module fits into a standard rack with a vector network analyzer and a spectrum analyzer.

Because modern communications systems require solid-state power amplifiers with high intercept points (wide dynamic range), the transistors used in these amplifiers must be characterized for their nonlinear (large-signal) behavior by means of load-pull testing. Load-pull testing of large quantities of RF transistors requires the generation of very low



2. The active load is emulated by processing the phase and amplitude of a DUT's output signals and feeding these signals back to the DUT.

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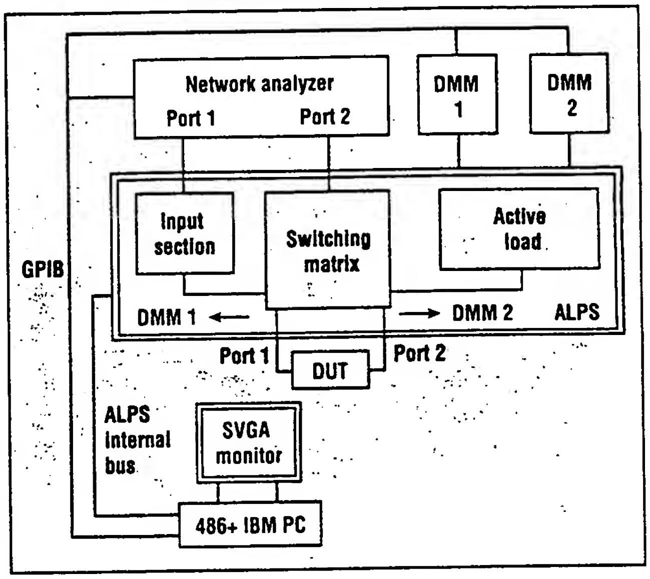

3. The ALPS architecture works with a VNA and a standard personal computer as a controller.

impedances (high reflection factors), high power-handling capability, control of harmonic impedances, fast and simple operation, and proper data management (see table).

Programmable tuners, both mechanical and electronic types, are limited in reflection-factor range. Mechanical tuners can be made to generate accurate reflection factors as high as 0.92 (equivalent VSWR of 25.0:1 or a minimum characteristic impedance, Z_{min}, of 2 Ω) in a frequency range (0.8 to 3.0 GHz) usable for most commercial communications applications. Electronic tuners offer less capability, with maximum reflection factors as high as 0.8 in a similar frequency range.

During load-pull measurements, a DUT must be presented with a real impedance that matches its internal impedance. Impedance interpolation is a questionable technique, whereas impedance extrapolation, although useful in noise-factor measurements, is not acceptable for load-pull testing. Active load-pull techniques eliminate this critical limitation with the capability of generating $\Gamma \geqslant 1$ at the DUT's reference plane, even if the connections between the test set and the DUT suffer high signal losses. The active load loop must have sufficient gain to generate amplitude levels that properly match a high-power DUT. With enough gain, this approach is well-suited for on-wafer testing of high-power devices.

Mechanical tuners can handle RF power levels of 100 W or more. This is not a critical factor for instrumentation involved in on-wafer testing, however, where the power levels are relatively low (from about 1 to 10 W). Existing solid-state power amplifiers or traveling-wave-tube amplifiers (TWTAs) can easily generate these power levels. Mechanical tuners are still the choice for testing high-power amplifiers generating more than 10 W, especially since high reflection factors are not required for these measurements.

Harmonic impedance tuning is more of a requirement for research and development (R&D) testing than for production applications. Transistor behavior at harmonic frequencies is often considered in the design of a power amplifier. Because mechanical or electronic tuners are designed as fundamental-frequency instruments, they are not suitable for harmonic impedance tuning. On the other hand, active load-pull testing permits the connection of parallel tuning loops that are tuned at the harmonic frequencies of a DUT's output port. The technique requires more costly equipment (such as RF synthesizers and components within the active load loop) than for fundamental-frequency tuning, but it has been proven experimentally.

Measurement speed is critically important for production testing, especially for devices targeted for commercial wireless applications in base stations and cell sites. Electronic tuners and active load-pull systems are designed for high-speed testing, both with a minimum of moving parts compared to mechanical tuners (which incorporate mechanical slug tuners driven by stepper motors). On average, electronic tuners and active load-pull systems provide about 5 to 10 times the measurement speed of mechanical tuners. This comparison depends not only on the speed of the tuners but also on the measurement method used. As an example, the ALPS approach requires about 150 s to tune

Comparing load-pull solutions

Requirement	Mechanical tuner	Electronic tuner	Active load-pull system
High reflection	$\leq$0.92 (2.1 Ω)	$\leq$0.82 (5 Ω)	>1 (0 Ω)
High power	>100 W CW	1 to 6 W	1 to 10 W
Harmonic tuning	No	No	Yes
Fast operation	No	Yes	Yes
Simple operation	No	No	Yes[1]
Data management	Yes[2]	Yes[2]	Yes[2]

[1] This depends upon the operation software, although the active load-pull system offers the potential of simple operation when the system is well-structured.
[2] An appropriate data-management software for this type of testing is possible, but as of yet is not commercially available.

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to 100 loads and to measure the power and efficiency at 10 different input-power levels per load (for a total of 1000 measurement points).

Systems based on mechanical and electronic tuners tend to be complex in calibration and operation, requiring the skills of experienced engineers. The ALPS measurement approach, however, does not require special components or calibration but operates with a vector network analyzer (VNA) as an integrated unit. Testing with an ALPS setup can almost be executed without an operating manual, due to an on-line "help" feature built into the test software.

The ALPS architecture (Fig. 1) employs an active load technique in which the output signal from the DUT is sampled, modified with respect to phase and amplitude, and is fed back into the output port of the DUT. This emulates a load for the DUT with precisely-controlled amplitude and phase (Fig. 2).

The ALPS system features a remotely-controlled input tuner which makes it possible to prematch the DUT at the input and save large amounts of injected power, which would otherwise be needed to drive the unmatched transistor into saturation. The ALPS system also includes a fully-calibrated reflectometer which makes it possible to measure the S-parameters of a DUT using the associated VNA as a non-calibrated receiver.

An ALPS setup can be divided into three sections: the input section, the switching matrix, and the active load (Fig. 3). The input section includes a driver amplifier to generate the test power level injected into the DUT, an electronic attenuator to adjust this level during load-pull testing, and a remote-controlled input tuner to prematch the device. The switching matrix includes a set of electronic switches to condition the injected and reflected signals to and from the DUT via directional couplers connected to the VNA. This section also includes the DC bias tees to provide voltage and current to the DUT. The active load section includes a directional coupler, a bandpass filter, a broadband phase shifter, an electronic attenuator, and a power amplifier. This section forms a signal-processing loop by retrieving part of the DUT's output signal, conditioning the signal's phase and amplitude, and reinjecting the modified signal into the DUT's output port to emulate a complex reflection factor (load).

The load-pull system connects to a VNA by means of two RF cables linked to the test ports. ALPS is compatible with all popular VNAs, including the HP 8510, HP 8720, and HP 8753 units from Hewlett-Packard Co. (Palo Alto, CA) and the 360 and 37000 analyzers from Anritsu

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Wiltron (Morgan Hill, CA). The system also works with a digital multimeter (such as the HP 34401 from Hewlett-Packard Co.) and a spectrum analyzer, such as the HP 70000, HP 8563, and HP 8566 from Hewlett-Packard Co.; the 2601, 2602, and 2613 units from Anritsu Wiltron; and the 3271 from Advantest (Buffalo Grove, IL).

Complete instrument control, calibration, and test procedures are managed by an external IBM personal computer which includes two ALPS control boards for the internal bus and one GPIB board for control of the instrumentation. The ALPS software is written in C++ programming language and operates under Windows 3.1 and 95 environments.

ALPS is straightforward to calibrate. It requires merely the connection of a few calibration standards to the test ports and a power meter at a calibration port. Then, the calibration routine is run, prompting the connection of different standards. Once calibrated, the ALPS system can be operated confidently without the need for further calibration for days at a time. The VNA need not be calibrated at the time of the ALPS calibration for effective active load-pull testing.

The ALPS measurement options are structured and simple: an operator has a choice of performing load-pull tests, S-parameter tests, or DC parameter tests. Load-pull testing includes power sweeps and automatic search for optimum performance in gain, power, or efficiency. Intermodulation and third-order intercept testing are also possible. S-parameter measurements are possible at higher power levels than are normally permitted by a VNA, since the test signals are decoupled by 10 to 20 dB. DC parameter testing includes output and transfer DC-curve measurements, as well as a combination of S-parameter measurements as a function of any DC-bias control.

An ALPS measurement set includes bias tees and two RF cables for connection to a DUT. For on-wafer and fixture testing, the transmission-reflect-line (TRL) calibration standards must be on-wafer, such as supplied by wafer-probe manufacturers, or in microstrip format. These standards should include a through and line.

Currently, the model ALPS-308 system is available for measurements from 0.8 to 2.8 GHz, covering most of the high-volume commercial communications applications. Certain measurement functions, such as DC parameter testing, intermodulation testing, and adjacent-channel power testing, are optional. **Focus Microwaves, Inc., 277 Lakeshore Rd., Pointe-Claire, Quebec H9S 4L2, Canada; (514) 630-6067, FAX: (514) 630-7466.**

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